United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

The Performance of FSCBG in Downwind Drift Predictions

FPM 93-9
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Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

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THE PERFORMANCE OF FSCBG IN DOWNWIND DRIFT PREDICTIONS

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1. Introduction and Model Background

The USDA Forest Service in cooperation with the U. S. Army has developed the Forest Service Cramer-Barry-Grim (FSCBG) aerial spray model incorporating the near-wake AGricultural DISPersal (AGDISP) model. FSCBG predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP near-wake representation solves a Lagrangian system of equations for the position and position variance of material released from each nozzle on the aircraft. The FSCBG far-wake representation begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover ground deposition. FSCBG includes an analytic dispersion model for multiple line sources oriented in any direction to the wind, an evaporation model for volatile spray components, an canopy penetration model for forest canopy interception, and an accountancy model to recover environmental fate of the released material.

Drop size distributions give the mass distribution of material as it is atomized by each nozzle. Drops containing volatile materials (such as water) begin to evaporate immediately upon entering the atmosphere, with the local temperature, relative humidity and relative wind speed determining the evaporation rate. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the spray material. Canopy deposition removes spray material from the air and prevents nonvolatile components from reaching the ground. Every aspect of the spray process is affected by the size and significance of atmospheric and aircraft-generated turbulence.

Meteorological calculations generate the background wind speed, temperature and relative humidity profiles. Evaporation calculations track the time rate of decrease of drop size. Canopy calculations remove additional material through impaction on vegetation. Near-wake calculations follow the behavior of released spray near the aircraft, and when out of wake influence or at the top of the canopy, hand off to the dispersion calculations to predict the dosage, concentration and deposition at user-designated downwind locations.

Model development began in the 1970s and lead to FSCBG version 1.0 (Dumbauld, Bjorklund and Saterlie 1980) containing only a "simple" wake-settling description of the spray aircraft (imposing a downwash velocity to the spray material atomized through the spray nozzles). Later development to version 2.0 (Bjorklund, Bowman and Dodd 1988) included the addition of a "complex" near-wake description incorporating the AGDISP model (Bilanin et al. 1989) and a hand-off criteria to transfer computational control from the near wake of the aircraft (generated by AGDISP equations) to the far wake (generated by FSCBG equations). This work was followed shortly by version 3.0, functionally identical code ported from mainframe to personal computer (Curbishley and Skyler 1989). Finally, version 4.0 (Teske and Curbishley 1991) revised the user interface and completely rewrote and streamlined the Fortran source code. Present technical aspects of the model are reviewed in Teske et al. (1993).

Throughout the development process, comparisons with field data played an important and essential role. Early comparisons with version 1.0 included downwind drift (Boyle et al. 1975) and deposition through a Southern forest canopy (Rafferty et al. 1982). Later comparisons with version 3.0 included downwind drift (Mickle 1987), open terrain and canopy penetration in Ponderosa pine (Rafferty and Bowers 1993), and

canopy penetration in Douglas-fir (Teske et al. 1991) and eastern oak (Anderson et al. 1992). Version 4.0 comparisons include downslope drainage winds in open terrain (Barry et al. 1993) and canopy deposition in Gambel oak (Rafferty and Grim 1992).

For the most part, model comparisons have been made within the aircraft swath and near the aircraft flight lines. Now, however, with continued and increased public awareness including the implications of pesticide drift, model emphasis has also expanded to focus more on downwind drift prediction capability. The present paper examines the ability of FSCBG to simulate drift conditions, the modifications needed to improve its predictive capability, and its subsequent agreement with specific field data.

2. Previous Drift Comparisons

Several FSCBG comparisons with downwind drift field data have been published previously. Three comparisons are reviewed here.

FAO SPRAY TRIALS

Spray trials sponsored by the Food and Agriculture Organization (FAO) of the United Nations were conducted at Dugway Proving Ground, Utah, in October 1974 to investigate the feasibility of using four-engine aircraft to disseminate insecticides, agricultural chemicals, or seeds over broad areas. A Douglas DC-7B aircraft was used in these trials, configured with a full-span spray boom mounted above the trailing edge of each wing. Two types of spray materials were used: a low-volatility solvent and No. 2 fuel oil. An oil red dye was added to the tank mix for the deposition measurement.

This study was initially reported in Boyle et al. (1975), re-examined in Rafferty and Bowers (1989), and revisited again by Rafferty and Bowers (1993). The relevant test parameters are given below:

Trial Number	Release Height (m)	Wind Speed at 32 m (m/s)
1-5	52.0	2.6
1-6	46.0	0.9
1-7	40.0	1.8
2-2R	45.7	3.2
2-3	27.4	4.6

A crosswind trial and an inwind trial are reproduced in Rafferty and Bowers (1993). Trial 1-5 (crosswind) comparisons are shown in Figure 1. Here the observed data are indicated by circles, and predictions for the three aircraft options available in FSCBG version 3.0 are displayed:

1. No Wake -- where the spray material is released vertically downward at its terminal velocity into the ambient crosswind.

2. "Simple" Wake -- where the aircraft is represented by a downwash velocity generated by the aircraft wingtip vortices.

3. "Complex" Wake -- where the aircraft near-wake is represented by the AGDISP model, and, when the vortices no longer influence the released spray material, the calculation is handed-off to the Gaussian dispersion model.

The importance of this comparison lies in the "capture" of the second peak in the deposition approximately six to ten km downwind of the spray release flight line by the Gaussian dispersion model, and the generally good qualitative agreement of model predictions with the data. The "complex wake" model appears to show a stronger crosswind influence, even though aircraft wake effects were considered relatively

unimportant (Rafferty and Bowers 1993). The other four trials (not shown here) give similar results, with better agreement achieved at higher wind speeds.

PROGRAM WIND FOREST SPRAY TRIALS

During the spring of 1986, an aerial spray dispersion experiment was conducted near Red Bluff, California, in conjunction with Phase III of Program WIND (Winds In Nonuniform Domains), a cooperative field meteorological study by the U. S. Army and the USDA Forest Service. The experimental site, a mixed conifer forest about 30 km east-northeast of Red Bluff, was chosen because the early morning drainage winds expected along this western slope of the Sierra Nevada mountains would carry sprayed material from the wooded area into the open. Six trials were conducted with a four-engine C-130 transport used by the U. S. Air Force in pest control, and four trials were conducted with a Bell 205 helicopter typical of the rotary-wing aircraft used by the USDA Forest Service in pest control. Both aircraft sprayed a mixture of water, glycerine, oil red dye, and manganese sulfate.

The results of this study were initially reported in Rafferty and Bowers (1989) and revisited by them in Rafferty and Bowers (1993). The relevant test parameters are given below:

Aircraft	Trial Number	Release Height (m)	Wind Speed at 28.4 m (m/s)
C-130	A-1	76.2	0.7
	A-2	76.2	2.4
	A-3	45.7	1.3
	A-4	76.2	1.8
	A-5	61.0	2.8 (at 30.2 m)
	A-6	61.0	2.3
Bell 205	B-1	45.7	2.6
	B-2	45.7	5.6
	B-3	45.7	2.1
	B-4	45.7	0.6

Two typical comparisons, again reproduced from Rafferty and Bowers (1993), are presented in Figures 2 and 3. In this study there are two independent data collection techniques: the oil red dye "spot count" and the manganese sulfate. Both techniques give similar results for all C-130 cases, as shown here, but the manganese sulfate appears to give incorrect results for the helicopter cases (Rafferty and Bowers 1993).

Whereas Figure 3 shows the "complex wake" model to improve downwind drift over the other two wake models, Figure 2 shows clearly that all three models fail to predict deposition beyond about one km. Results are again poor when wind speeds are low or aircraft release heights are uncertain. The other trials (not shown here) give similar results.

DUNPHY TRIALS 1984 AND 1986

In 1981, the National Research Council (Canada) began a series of coordinated experiments under the auspices of the New Brunswick Spray Efficacy Research Group to establish the effects of meteorology on off-target drift (Crabbe et al. 1982). These experiments culminated in two sets of experiments near Dunphy Airstrip in 1984 and 1986 to assess the effects of meteorology and operational parameters on deposit and drift. Four trials from the complete data set are summarized below (from Picot, Wallace and Kristmanson 1987):

Trial Number	Release Height (m)	Wind Speed (m/s)
3-84	52.0	4.5
2-86	44.5/63.0	6.6/7.6
6-86	36.0/35.1	4.2/4.1
7-86	42.2	4.3

These data have received recent attention by Mickle 1987. The comparisons for Trial 6 are shown in Figures 4 and 5 for the two aircraft used, a TBM and an AgTruck. In these figures the deposition data is compared with predictions from FSCBG, an early version of AGDISP (whose solution algorithm has since been modified to permit a more rapid calculation of droplet trajectories), and the finite difference PKBW model (Picot, Wallace and Kristmanson 1987). In both cases shown here, FSCBG version 3.0 does an excellent job of predicting the downwind deposition of spray material. Similar results were also obtained for the other trials conducted at Dunphy.

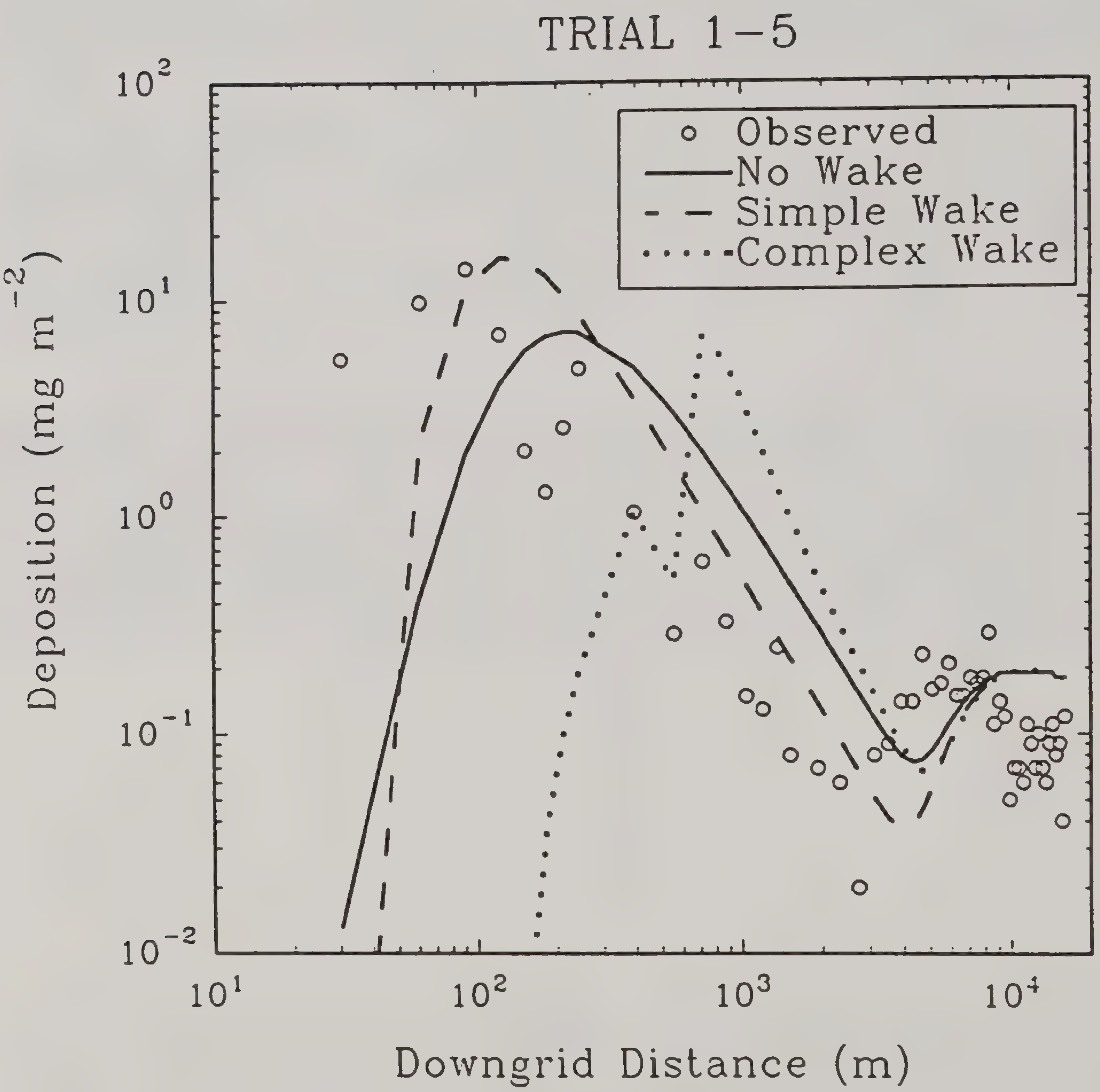

Figure 1. Comparison of deposition measurements with deposition profiles calculated by FSCBG with no wake effects, simple wake effects, and complex wake effects, for FAO spray trial 1-5, a crosswind dissemination by the DC-7B. Plotted results are from Rafferty and Bowers (1993). Both plot scales are logarithmic, emphasizing differences near the spray release line and for smaller deposition levels, and compressing them elsewhere.

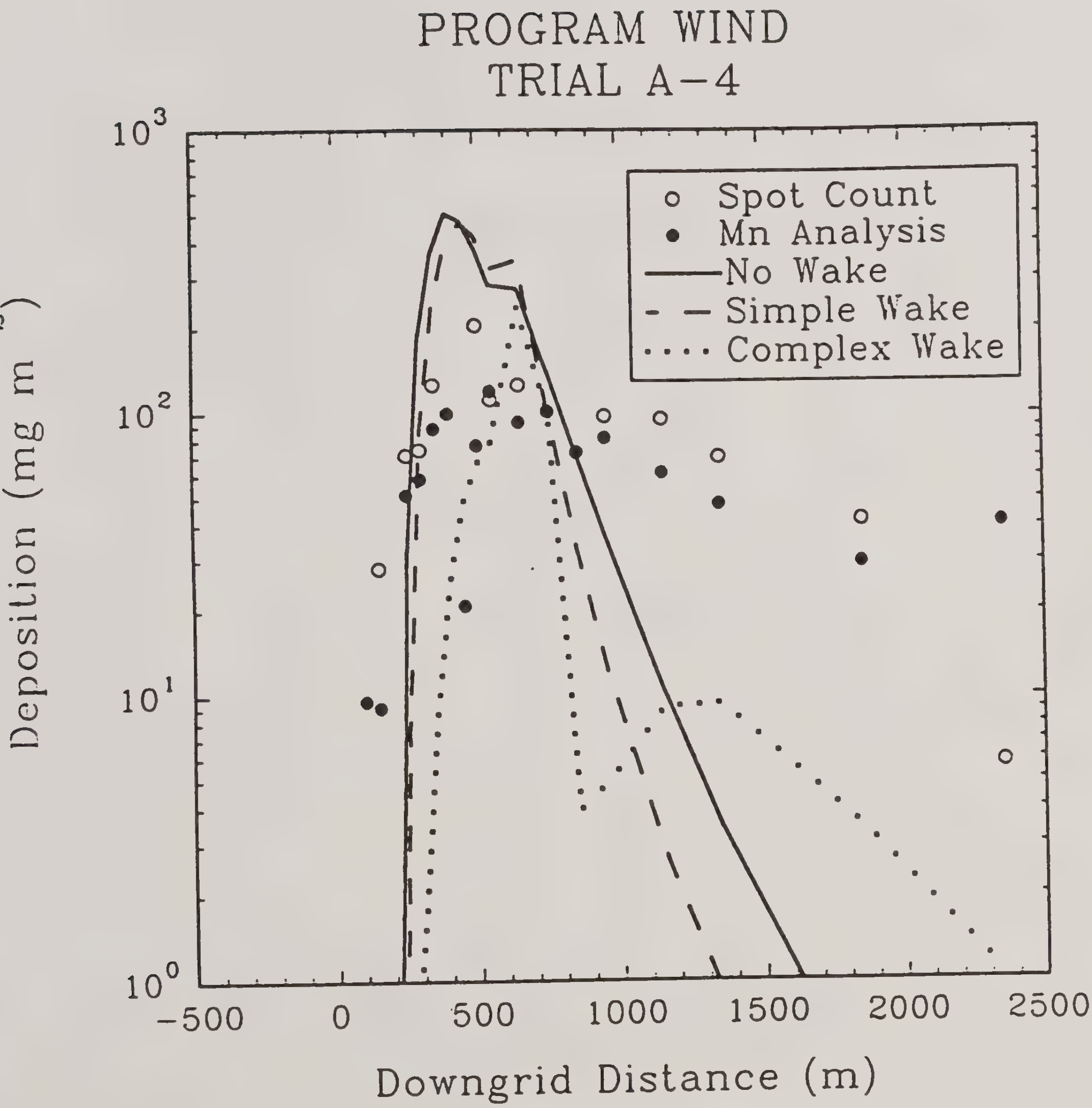

Figure 2. Comparison of deposition measurements with deposition profiles calculated by FSCBG with no wake effects, simple wake effects, and complex wake effects, for Program WIND spray trial A-4, a crosswind dissemination by the C-130. Plotted results are from Rafferty and Bowers (1993). The vertical plot scale is logarithmic. "Spot Count" are results from Mylar sheets for the oil red dye; "Mn Analysis" are results for the manganese sulfate.

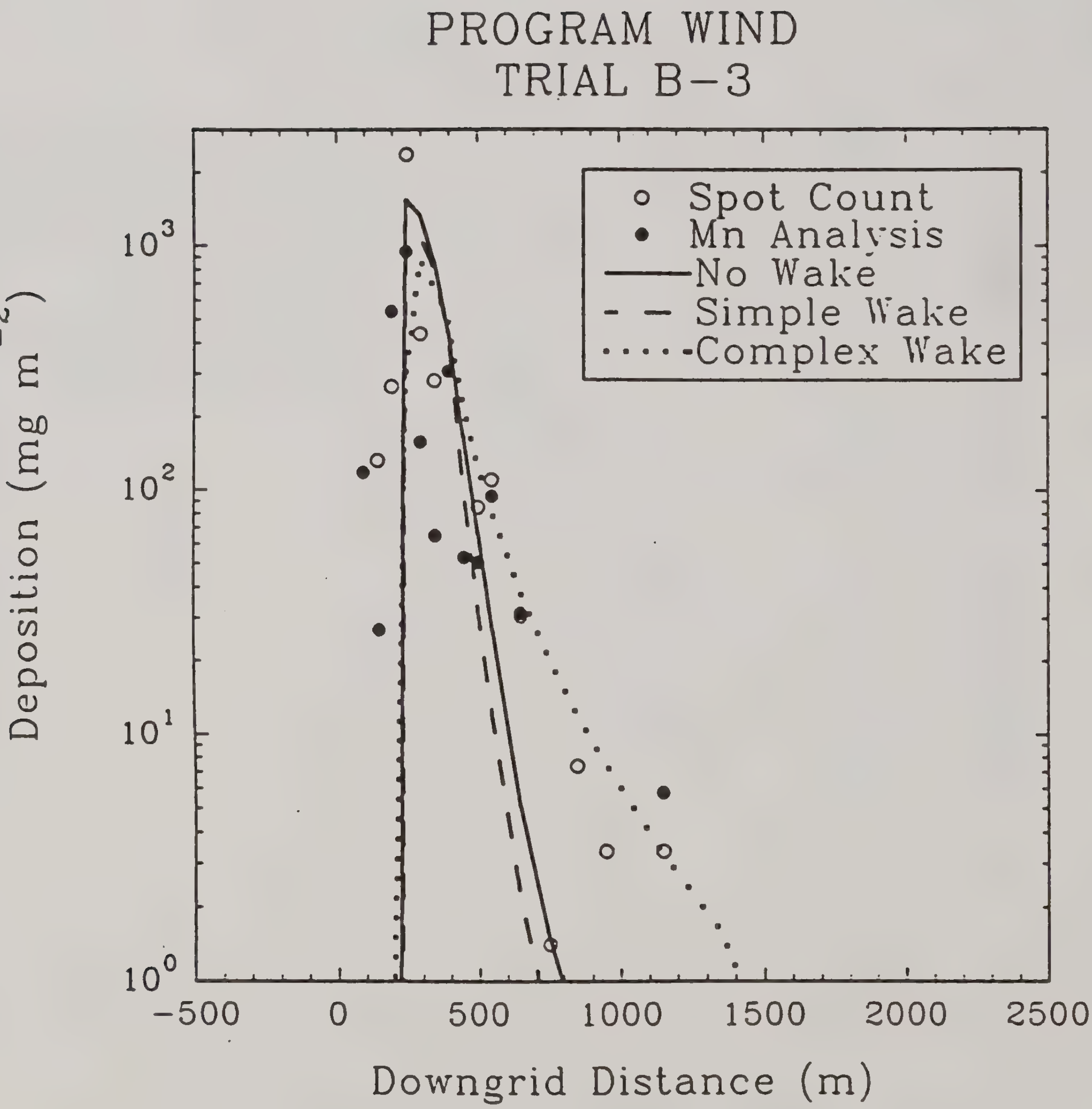

Figure 3. Comparison of deposition measurements with deposition profiles calculated by FSCBG with no wake effects, simple wake effects, and complex wake effects, for Program WIND spray trial B-3, a crosswind dissemination by the Bell 205 helicopter. Plotted results are from Rafferty and Bowers (1993). "Spot Count" and "Mn Analysis" are described in Figure 2.

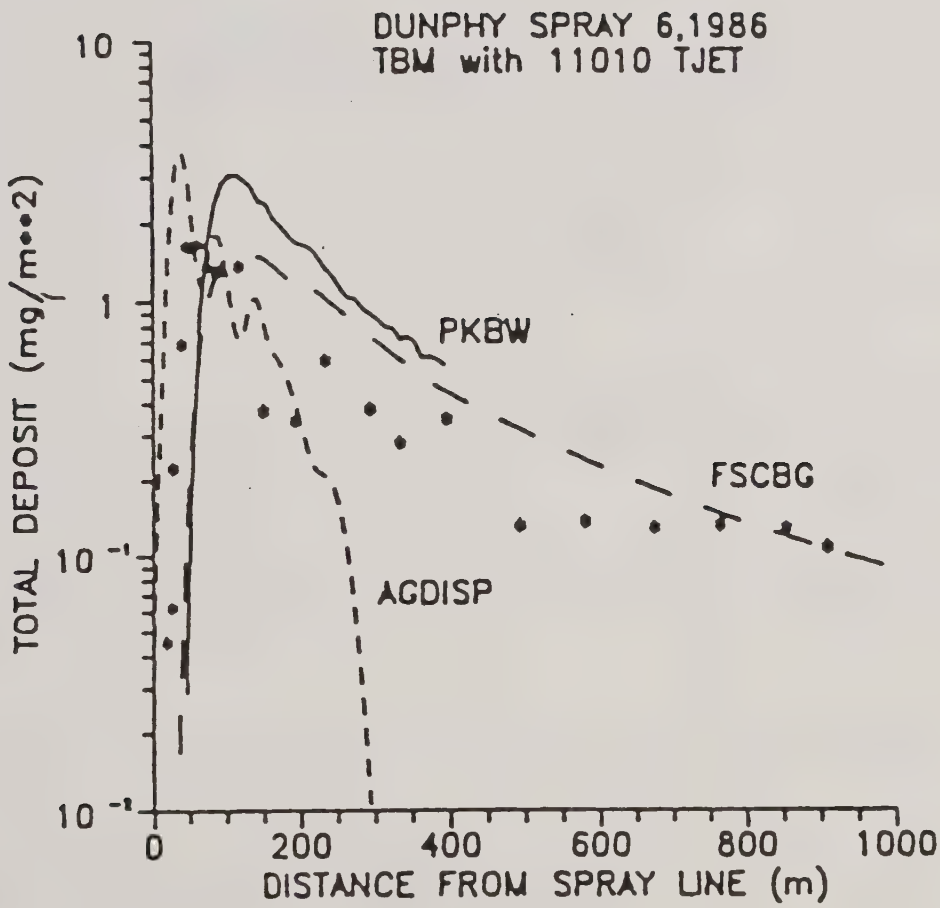

Figure 4. Comparison of deposition measurements with deposition profiles calculated by FSCBG and AGDISP for Dunphy spray trial 6 for the TBM. PKBW (also shown) is a finite difference simulation of the vortex wake of the spray aircraft in ground effect (Picot, Wallace and Kristmanson 1987). Plotted results are from Mickle (1987).

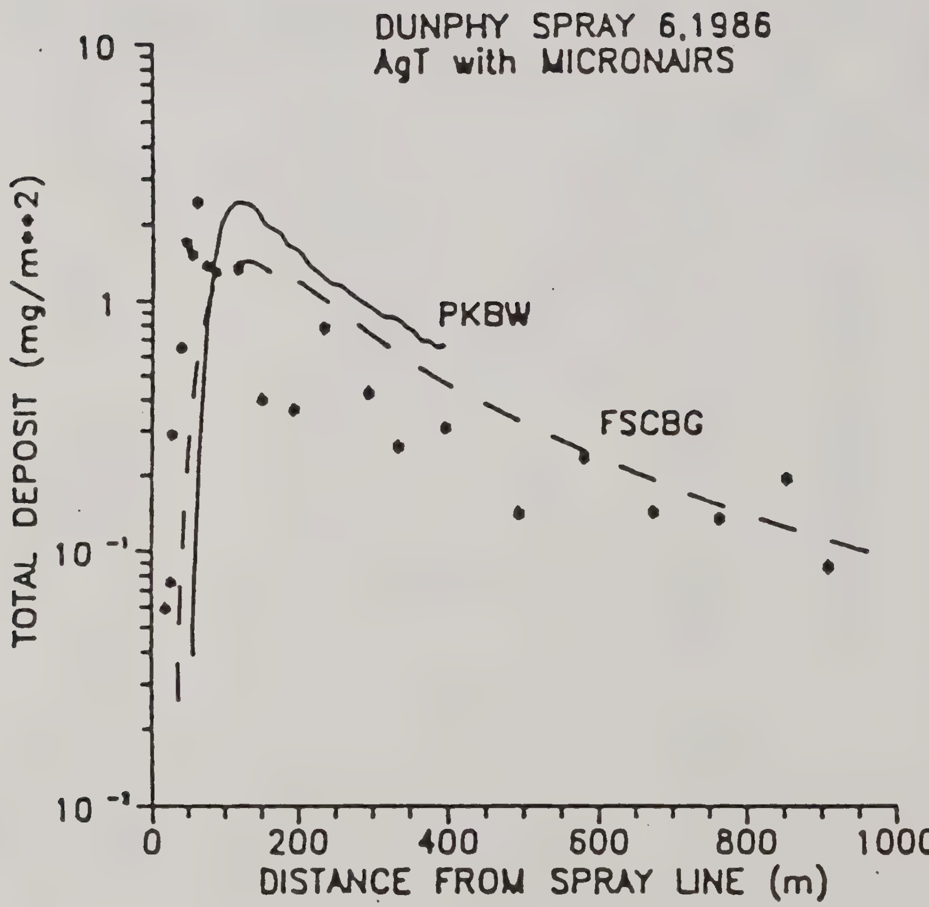

Figure 5. Comparison of deposition measurements with deposition profiles calculated by FSCBG for Dunphy spray trial 6 for the AgTruck. PKBW is described in Figure 4. Plotted results are from Mickle (1987).

3. Problem Description

The three data sets discussed above would suggest that FSCBG accurately predicts downwind drift. However, more recent data has appeared which do not compare as favorably with FSCBG predictions. These data, by B. Richardson of New Zealand, Dow Elanco, and the Spray Drift Task Force, suggest that the downwind drift predictions of FSCBG need re-examination. For example, the results shown for the DC-7B trials and the Program WIND trials all appear to give poor qualitative agreement at lower wind speeds.

Downwind drift may be characterized by the behavior pattern illustrated in Figure 6. Here, typical flight lines (flown at lane separation) lay down spray material. The in-swath deposition recovers the desired on-target deposition levels (near 0 downwind distance). Downwind (the wind in this example is from left to right), the buffer zone is reached, and a significant drop in deposition occurs, followed by a much more gradual downwind deposition decay. All of the plots shown in previous figures exhibit the behavior illustrated in Figure 6. Downwind drift behavior can be quantified only by plotting results on a logarithmic deposition scale as shown here.

After considerable investigation, several conclusions have been reached regarding the proper prediction of downwind deposition in FSCBG. These are:

1. Higher wind speeds and higher release heights correlate with the ability of FSCBG to predict downwind drift more accurately. It would appear likely, then, that cases of strong evaporation (high temperature and low relative humidity) would also enhance the chances of the model to predict drift. These three conditions (higher wind speed, higher release height, and stronger evaporation) all tend to produce smaller spray drops that move farther downwind before depositing. An accurate inclusion of these smaller drop sizes is therefore important when modeling downwind drift. Field conditions sensitive to these variables (Teske and Barry 1993) will give better agreement between the model and the data.

2. Finer drop size distributions enhance model predictions in drift. For the present study it appears that significant improvement in downwind deposition can be achieved by splitting the spray drop size distribution (from a wind tunnel test) into size classes that each contain no more than two percent of the total mass fraction. Since curve-fitting techniques (Teske 1992) generally smooth the distribution function (and may move mass to where it should not be), it appears best to work with the original wind tunnel distribution, expanding to the smallest drop size possible, and interpolating between size classes by volume (interpolating on diameter cubed rather than diameter) to generate a modified spray drop size distribution for FSCBG. This step may generate up to 100 drop size categories, significantly increasing the computer time needed to run the model. However, this operation is considered essential to critical downwind drift comparisons. In cases where the wind tunnel tests do not provide detail of the drop size distribution below 50 micrometers, the root/normal technique (described in Teske 1992) must be considered.

3. All nozzles present on the aircraft should be included in the FSCBG simulation. The practice of combining nozzles, while maintaining the same total application and flow rate, should not be tried here, since each nozzle acts as a spray material source subject to a slightly different vortical wind field. This hypothesis will be tested in later research.

4. The hand-off from the near-wake model (AGDISP) to the far-wake model in FSCBG must be clearly defined, and the technique refined accordingly. In all that follows, the near-wake calculations are taken to ground deposition, and model comparisons are then made. The hand-off mechanics have changed through the several versions of FSCBG, and it appears now that this area demands a deliberate examination. Rules for the application of a user-defined hand-off criteria should be based on meteorological conditions and release height; its detail is not yet decided, but is forthcoming.

In what follows, several available drift data sets have been compared with FSCBG predictions incorporating the above suggestions.

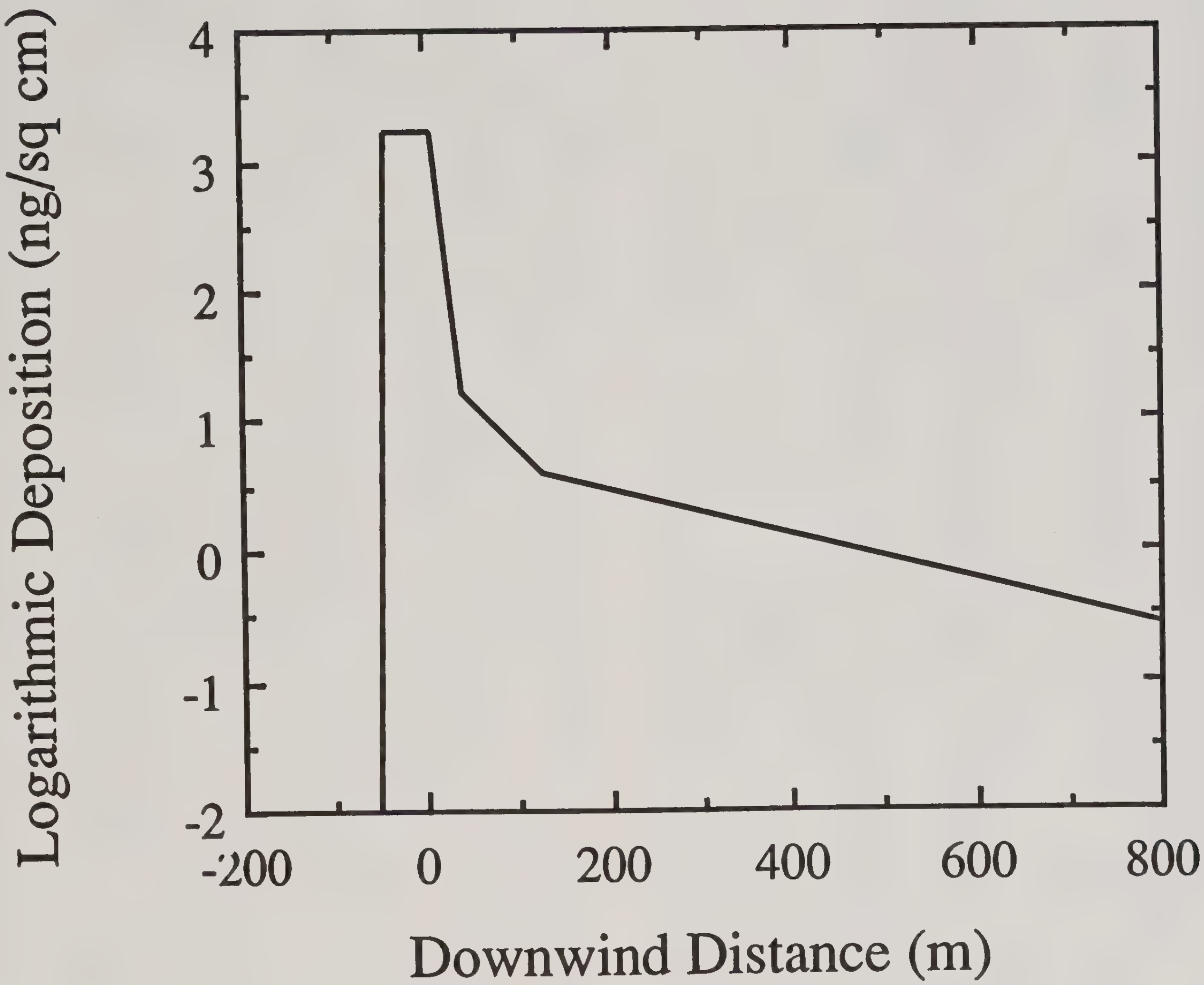

Figure 6. Typical deposition pattern downwind of several spray lines released upwind of location 0. The ambient wind is from left to right. The vertical scale is logarithmic. The in-swath region drops quickly through the buffer zone to a gentle downwind deposition into the far field.

4. Additional Data Comparisons

Several data sets are examined with the downwind drift corrections suggested in the previous section of this report. Their results are described below.

PROGRAM WIND TRIAL A-4

First it may be best to re-examine trial A-4, shown originally by Rafferty and Bowers (1993) and reproduced here as Figure 2. Rafferty and Bowers (1989) examined the canopy deposition, since the spray material was released over the forest. Here, we choose to neglect the trees and examine the open field predictions further downwind. Table 1 summarizes the open field test conditions found in Rafferty and Bowers (1989). Figure 7 compares the near wake model predictions with the data, where the release height has been adjusted (A. Bilanin, private communication), wind speeds extrapolated to the adjusted release height, and the drop size distribution (from Skyler and Barry 1990) expanded to 63 categories using the root/normal technique (Teske 1992). It may be seen that the predictions more nearly match the data than the comparisons plotted in Figure 2.

A typical way to compare predictions and data is by means of a correlation coefficient (Guttman, Wilks and Hunter 1971) defined as:

$$R^2 = \frac{\sum(x_1 - \bar{x}_1)(x_2 - \bar{x}_2)}{\sigma_1 \sigma_2} \tag{1}$$

where x_1 and x_2 are the model predictions and the data, respectively, σ_1 and σ_2 are the standard deviations of the model predictions and the data, respectively, and an overbar denotes an average value. The value of R^2 may range between -1 and 1, depending on whether the predictions and data are completely uncorrelated, to completely correlated. Application of Eq. (1) to this field test yields a correlation coefficient of:

$$R^2 = 0.762$$

Since coefficients of 0.8 and above are considered quite good when comparing field data, it may be concluded that the revised FSCBG model does an excellent job of predicting this data set.

NEW ZEALAND FIELD STUDY

In an effort to validate the predictions of FSCBG in aerial applications consistent with their particular needs, the New Zealand Forest Research Institute conducted a series of field tests in 1991, and provided preliminary reporting on their work at the September meeting of the National Spray Model Advisory Committee, Blacksburg, Virginia (Richardson 1991). Their comparisons were not particularly favorable. Subsequently, it

was determined that some logic in FSCBG version 3.05 could have lead to these erroneous predictions. Following up on this, Richardson replied by letter (B. Richardson, private communication) that in virtually all twelve field trials the same trends are apparent: the value of the modeled peak deposition was close to the data, but four to eight meters downwind; and prediction of drift matches the data quite well in most cases to 300 m downwind. Richardson concluded, "with the earlier version [of FSCBG] the position and size of peak deposition closely matched the data but drift was well underpredicted. Now, in general, FSCBG [version 4.0] drift predictions seem to be much better but we have lost some precision close to the aircraft."

One of the figures in his letter is reproduced as Figure 8, and it may be seen that data comparison is excellent. Further to this exchange, Richardson presented his findings in a model comparison report (Richardson et al. 1993), an informational document on the use of FSCBG in New Zealand (New Zealand Forest Research Institute "What's New in Forest Research" No. 228: Aerial Spraying by Computer 1993), and a conference preprint (Ray et al. 1993).

Richardson included one set of data with his original letter. The field test conditions are summarized in Table 2. The nozzles were D8 Jet, oriented at zero degrees to the air stream. Since the actual drop size distribution was not known, the data base values from Skyler and Barry (1990) were used in the simulation, and interpolated by the root/normal technique (Teske 1992) to include 99 drop size categories. Comparison with data is given in Figure 9, where it may be seem that the revised FSCBG model does a remarkable job of predicting the data downwind to 100 m, and then falls off appreciably for the last four data points (the last data point suggests an increase in deposition over upwind points, which is not physically possible). It is suggested here that the drop size distribution needs careful re-examination, and that the data should be scrutinized as well. Considerable effort at model input changes did little to improve the predictions of FSCBG at the last four data points. The correlation coefficient, from Eq. (1), gives:

$$R^2 = 0.644$$

DOW ELANCO DATA

The Spray Drift Task Force originally compared FSCBG predictions with predictions made by a drift model developed by Dow Elanco (Gaidos et al. 1990). The Dow-Elanco model is proprietary; however, the 1990 publication did contain enough information on three field data sets to consider examination here by FSCBG.

Information on the three data sets is summarized in Table 3. In all cases D12-46 nozzles were used. The authors supply the three drop size distribution parameters needed to recover the drop size distribution using the upper-limit function of Mugele and Evans (1951) which curve fits the cumulative volume fraction to an error function. It is anticipated that the smaller drop sizes are responsible for drift, hence, the curve fits were initiated at 10 micrometers in each case. Figures 10, 11 and 12 demonstrate the comparisons with data. Treatment A is underpredicted beyond 100 m, while Treatments B and C are well-predicted by the model. The correlation coefficients for these three data sets are:

A: $R^2 = 0.746$

B: $R^2 = 0.794$

C: $R^2 = 0.632$

SPRAY DRIFT TASK FORCE DATA

From July 9 to August 8, 1992, the Spray Drift Task Force conducted a series of 72 field trials with an AgHusky and an Air Tractor AT502. Nominal release heights were 1.5 m over 20.0 cm grass, in crosswinds of 0.9 m/s to 6.7 m/s. Tracer amounts of diazinon and malathian were deposited on cards with four aircraft flight lines (flown at lane separation). A summary of the meteorological conditions may be found in document PSL-92/74 from the Physical Science Laboratory, New Mexico State University, Las Cruces, New Mexico. Drop size distribution data began at 4 micrometers (Esterly et al. 1993), and volume-interpolated as described previously. The deposition and drop size distribution data are proprietary.

In communication with the Spray Drift Task Force statistician (G. Krause, letter report, 23 April 1993), an analysis of correlation (similar to Eq. (1) but with a commercially available statistical package) was undertaken on the comparison of the data with predictions made by the near-wake model of FSCBG, corrected for the effects considered here. The various assumptions, and their statistical results, are as follows:

1. Inclusion of all data (across the card collectors from -104 m to 792 m downwind):

$$R^2 = 0.702$$

2. Exclusion of data beyond 137 m:

$$R^2 = 0.655$$

(not an improvement; the revised near-wake model is accurate downwind as well)

3. Excluding questionable data points that fit certain statistical criteria:

$$R^2 = 0.883$$

(outlying data points must not have been interpreted correctly when the sample cards were read by the processing laboratory)

4. Excluding upwind data points:

$$R^2 = 0.898$$

(marginal improvement, although the revised results tend to confirm that the precise swath displacements may not have been flown by the spray pilot).

These results confirm the accuracy of the revised near-wake FSCBG model.

ADDITIONAL DATA COMPARISONS

Two pioneers in the aerial application field, W. E. Yates and N. B. Akesson, both from the University of California, Davis, California, conducted many field tests on spray behavior from the mid-1960s until their retirements in the 1980s. In almost all cases they were looking for effects related to the behavior of released material under specifically defined conditions. At times their field test procedures were not sufficiently detailed to revisit with model predictions once these models became available.

Bird (1992) recently reviewed the status of low-flight agricultural data, and several examples of their work (Yates, Akesson and Coutts 1967; Yates, Akesson and Cowden 1974). Unfortunately, the data needed to run the model is only partially explained in either paper. Recently, however, Akesson, Hitch and Jones (1992) summarized several downwind drift analyses; in particular, these authors cited a spray drift study from Desert Ranch, Melbourne, Florida, that is detailed in Semmes, Cromwell and Shoup (1990). This data set becomes the final data set examined in this report.

The study evaluated three aerial spray systems for drift potential under typical Central-South Florida meteorological conditions. All three applications were made with an Air Tractor, but with three nozzle configurations: Micronair AU3000 rotary atomizers, D8-46 hollow cone nozzles, and D8-Jet nozzles. Since field results are quite similar, the D8-46 nozzle runs are predicted here, with the drop size distribution from Skyler and Barry (1990) extrapolated by the root/normal technique (Teske 1992) to generate 69 drop size categories. Table 4 summarizes the input conditions to the revised near-wake FSCBG model, and Figure 13 compares results. It may be seen that the data trend is similar, although the very small deposits recorded and predicted (over six orders of magnitude from the in-swath deposition value) lead to the prediction of many spikes in the deposition pattern where individual drops impact the surface. It would appear appropriate to transition to a Gaussian dispersion model by 1000 m or so. The correlation coefficient for the several data points recorded is:

$$R^2 = 0.982$$

Table 1. Field Test Conditions for Program WIND Trial A-4.

Aircraft Type	C-130
Weight	51000.0 kg
Wing Span	40.41 m
Propeller RPM	2200.0
Propeller Efficiency	0.8
Planform Area	157.19 m^2
Drag Coefficient	0.1
Number of Nozzles	50
Nozzle Type	8020
Nozzle Angle	90 deg
Spraying Speed	103.0 m/s
Release Height	152.4 m
Volatile Fraction	0.0
Emission Rate	99.0 mg/m per pass (2 passes)
Spray Passes	150 and 225 m downgrid distance
Wind Speed at 30.2 m	2.8 m/s in the open
Wind Direction	95 deg (nearly crosswind)

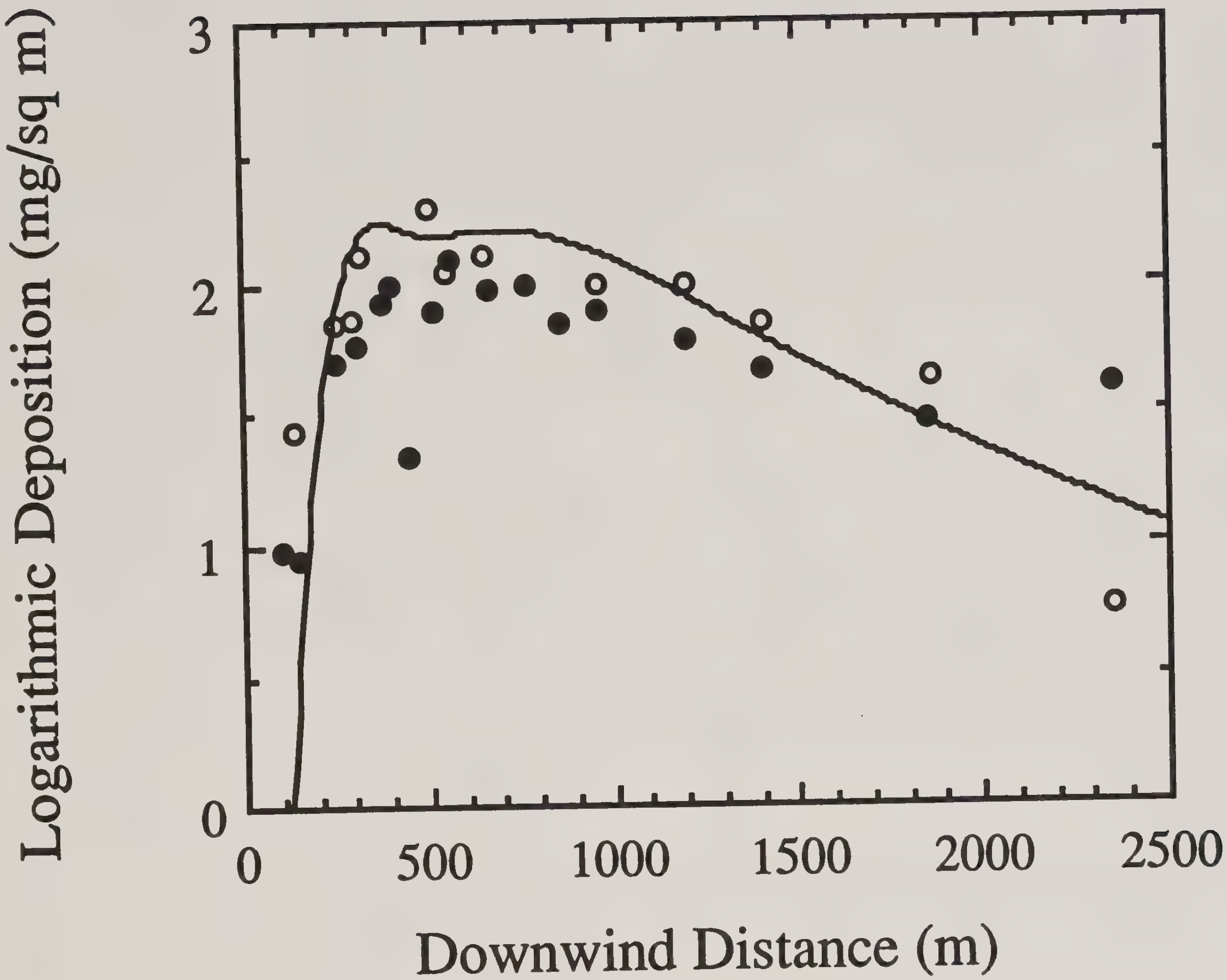

Figure 7. Comparison of the revised near-wake model prediction of FSCBG with Program WIND spray trial A-4. Data is circles (see Figure 2); model prediction is solid curve.

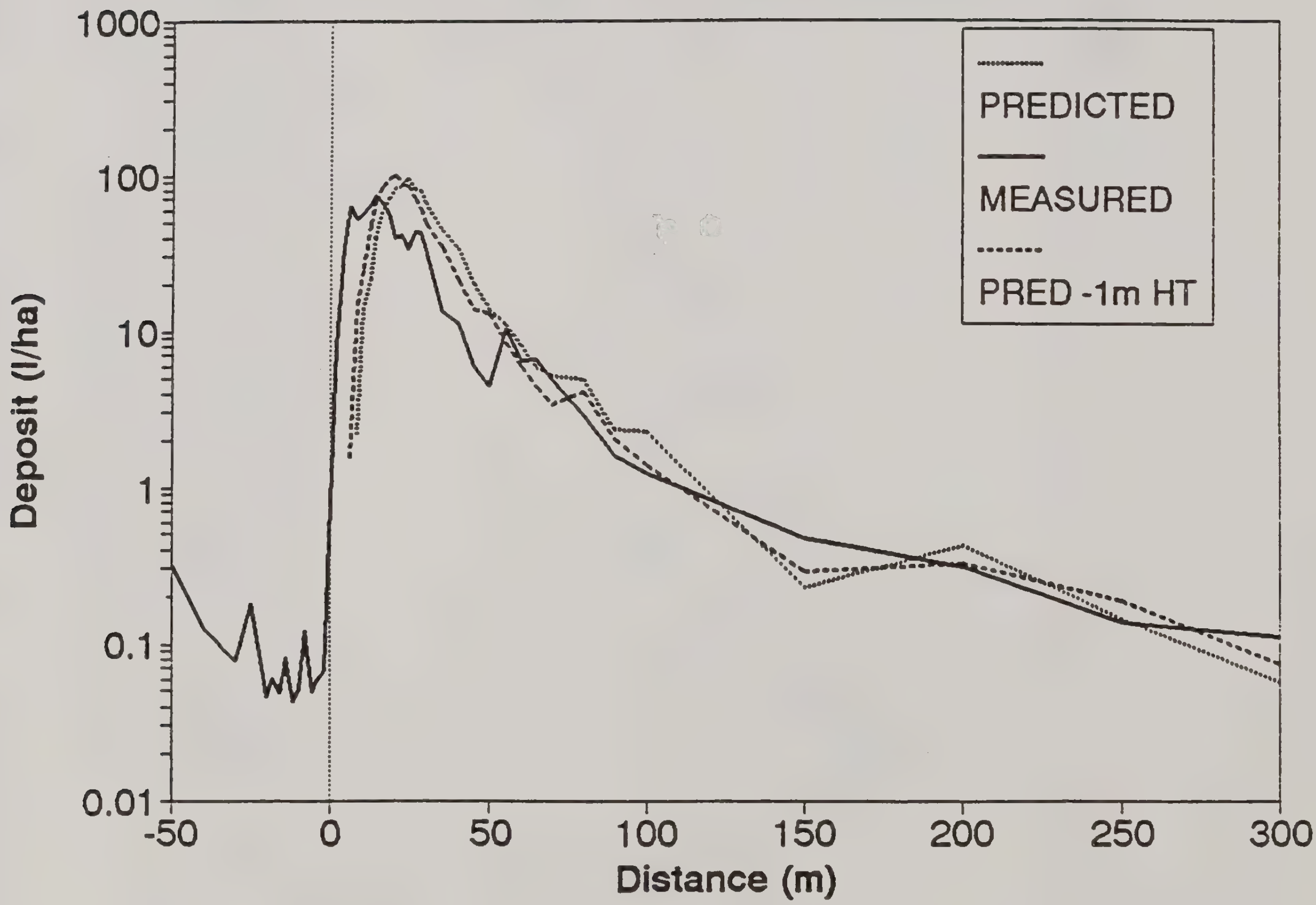

Figure 8. Comparison of FSCBG predictions with New Zealand field study data run A for the D8-45 nozzle. Curves are shown for measured data and model predictions, with a sensitivity in release height of one meter.

Table 2. Field Test Conditions for the Richardson Data Set.

Aircraft Type	Bell JetRanger
Weight	1300.22 kg
Rotor Diameter	10.16 m
Blade RPM	350.0
Nozzle Horizontal Locations	± 3.91; ± 3.64 ; ± 3.17 ; ± 2.83 ; ± 2.37 ; ± 1.92 ; ± 1.45 ; ± 1.03 ; ± 0.31 m
Nozzle Vertical Location	- 2.7 m
Specific Gravity	1.0
Volatile Fraction	0.99
Spraying Speed	22.7 m/sec
Release Height	19.35 m
Emission Rate	116.5 l/min per pass (3 passes)
Ambient Pressure	996.0 mb
Average Wind Speed	4.51 m/sec
Average Temperature	14.3 deg C
Average Relative Humidity	50.5 percent
Nozzle Type	D8 Jet
Nozzle Angle	0.0 deg

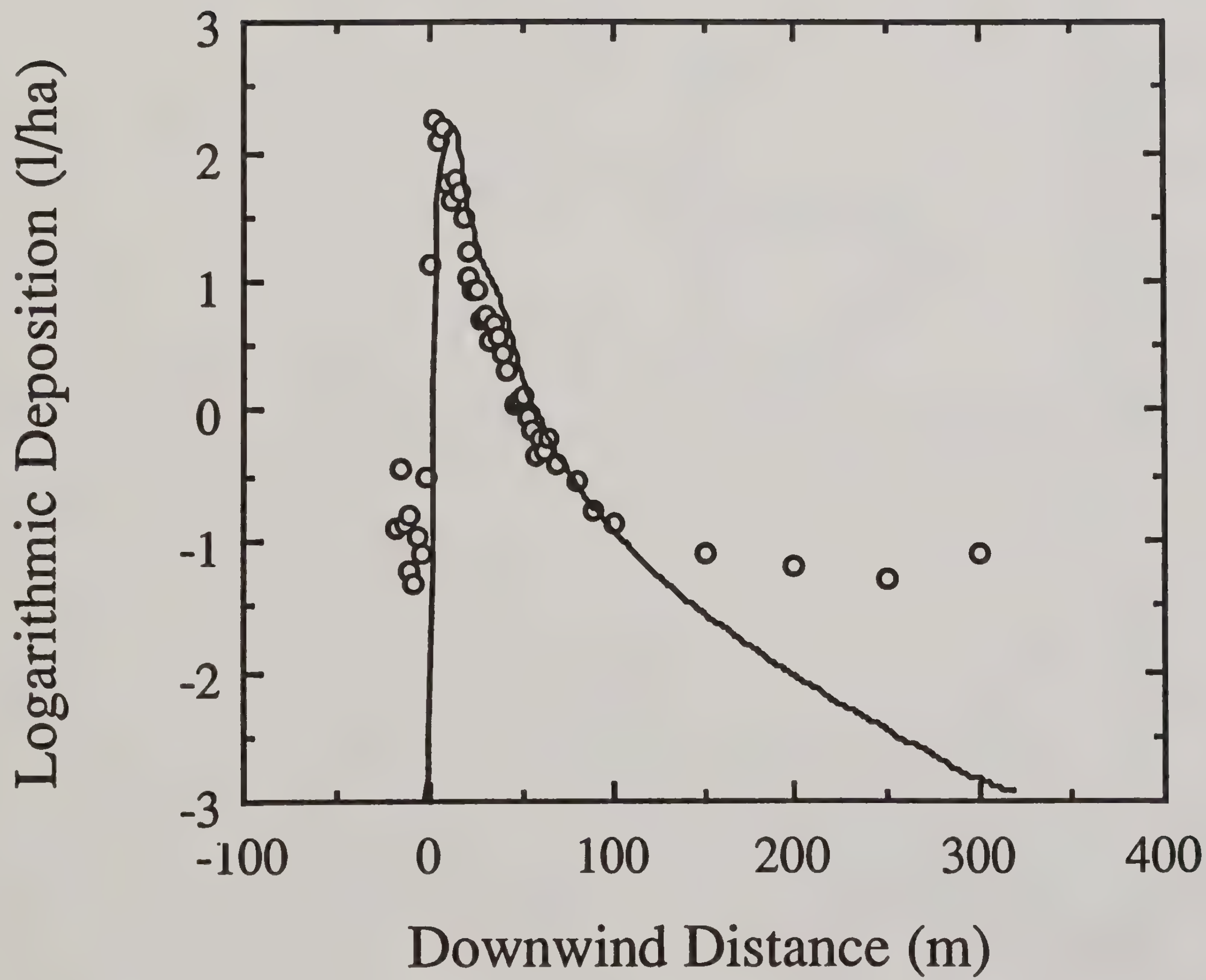

Figure 9. Comparison of the revised near-wake model prediction of FSCBG with the supplied Richardson field data. Data is circles; model prediction is solid curve.

Table 3. Data Set Information for the Dow Elanco data.

	Treatment Designation		
	A	B	C
Aircraft	Ag Cat	Air Tractor	Ag Cat
Volatile Fraction	0.991	0.978	0.921
Active Ingredient (kg/ha)	0.370	0.247	0.258
Spraying Speed (m/s)	44.7	58.1	44.7
Release Height (m)	6.0	6.0	6.0
Emission Rate (l/ha)	81.4	54.3	57.1
Swath Width (m)	15.2	15.2	15.2
Average Wind Speed (m/s)	4.0	4.0	4.5
Average Temperature (deg C)	28.9	26.7	33.9
Average Relative Humidity (percent)	50.0	70.0	34.0
<u>Drop Size Distribution Parameters</u>			
Dmax (µm)	1400	1300	700
A	2.139	2.474	1.210
δ	1.170	1.254	1.163
Number of Drop Size Categories	89	85	91

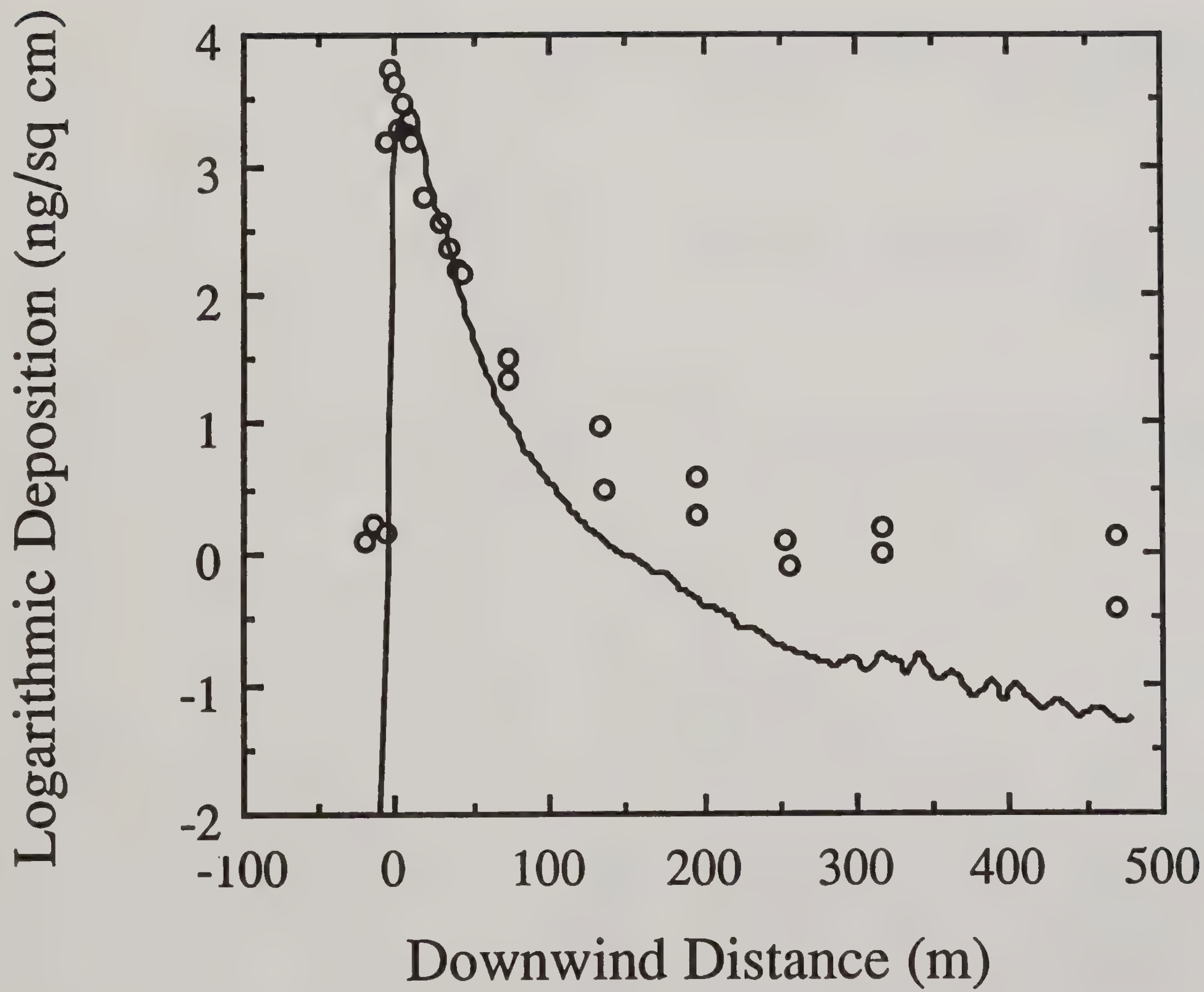

Figure 10. Comparison of the revised near-wake model prediction of FSCBG (solid curve) with the drop size data of Dow Elanco Treatment A (circles).

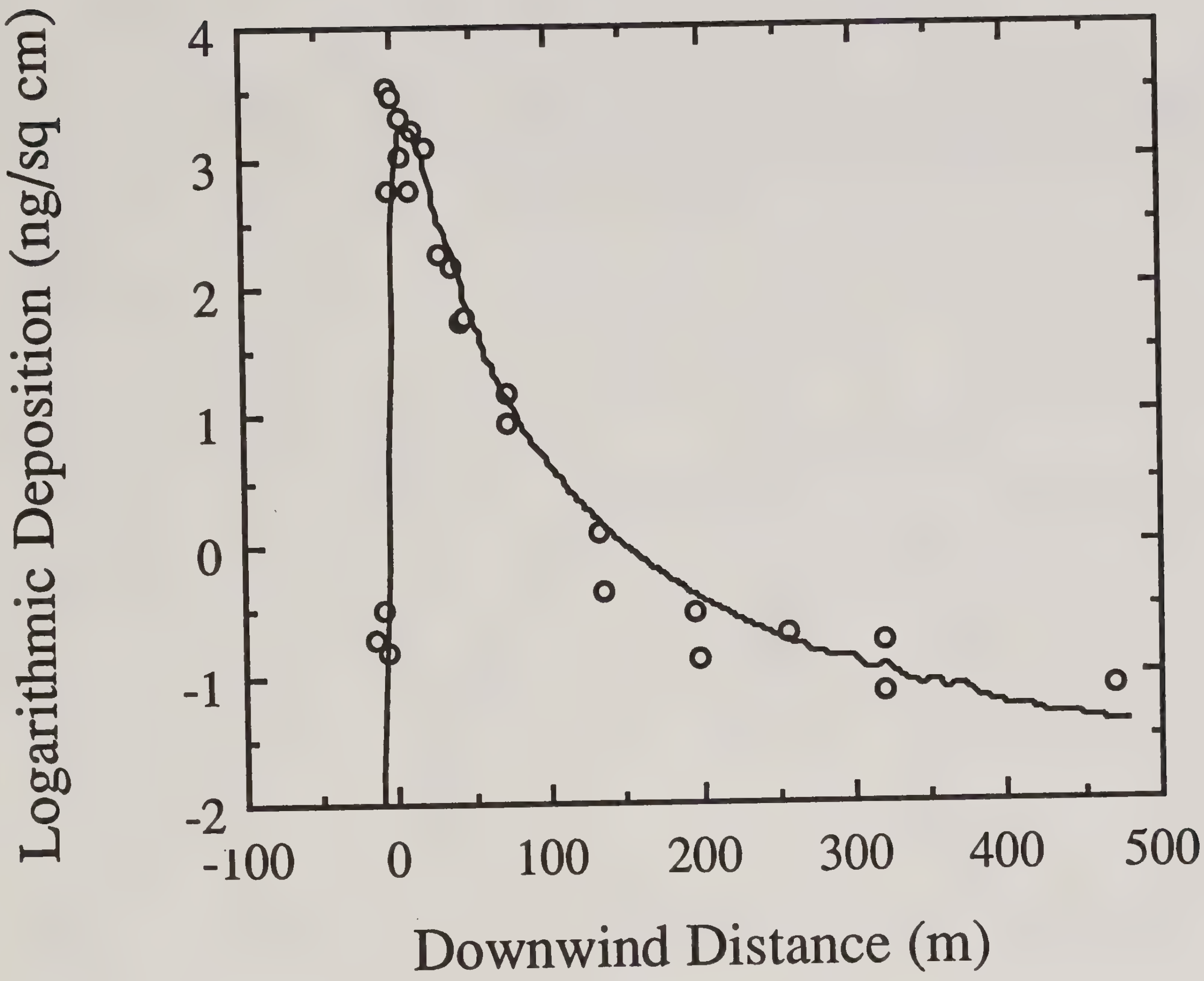

Figure 11. Comparison of the revised near-wake model prediction of FSCBG (solid curve) with the drop size data of Dow Elanco Treatment B (circles).

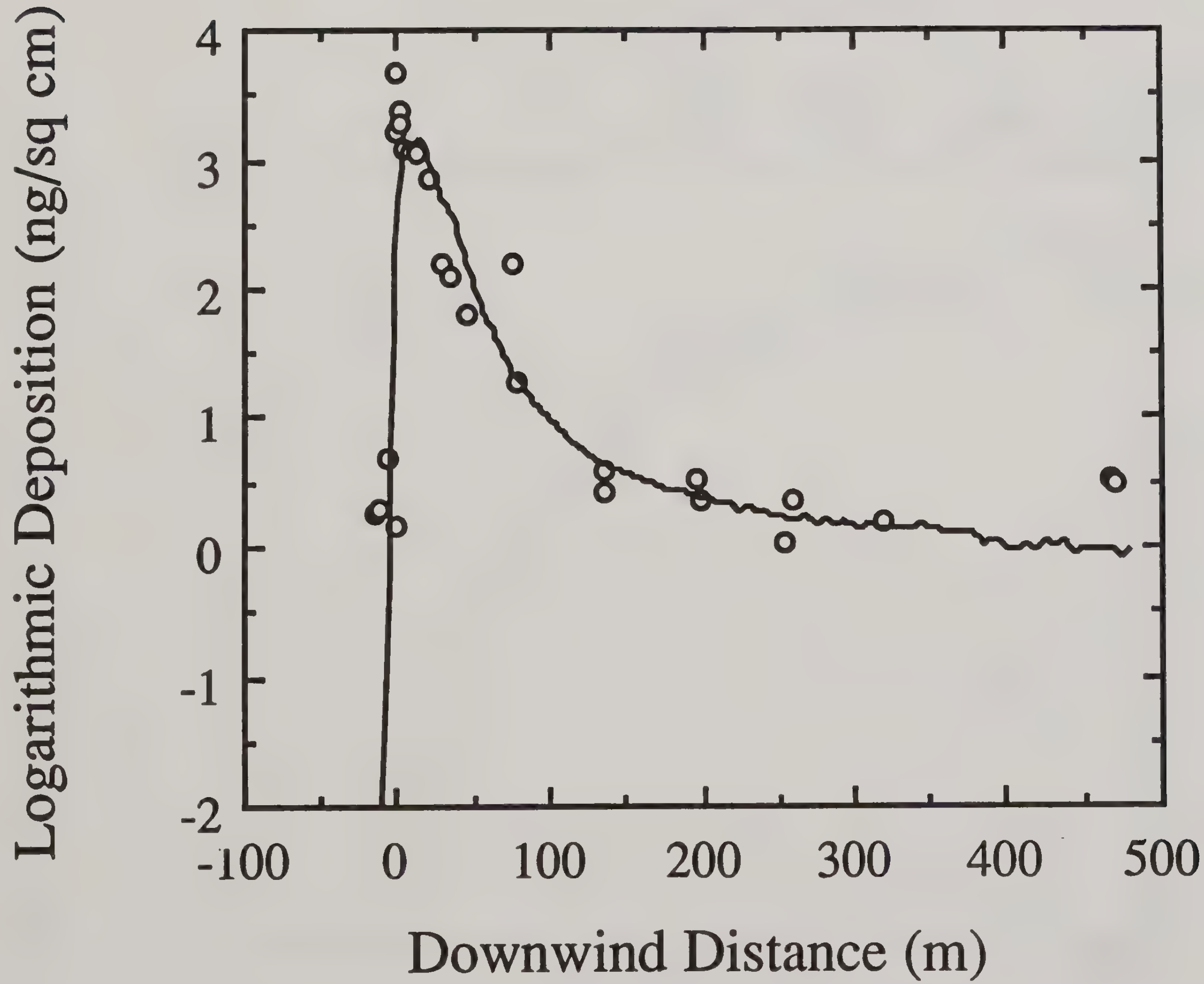

Figure 12. Comparison of the revised near-wake model prediction of FSCBG (solid curve) with the drop size data of Dow Elanco Treatment C (circles).

Table 4. Test Data for Desert Ranch, Run II.

Aircraft Type	Air Tractor
Aircraft Weight	2586.7 kg
Wing Span	13.78 m
Nozzle Type	D8-46 (34 nozzles)
Nozzle Angle	0 deg
Spraying Speed	53.3 m/s crosswind
Release Height	3.7 m
Application Rate	195.0 l/min per pass (10 passes)
Average Wind Speed	1.79 m/s (at 6.0 m) crosswind
Average Temperature	31.1 deg C
Average Relative Humidity	80.0 percent
Volatile Fraction	0.938
Specific Gravity	1.0

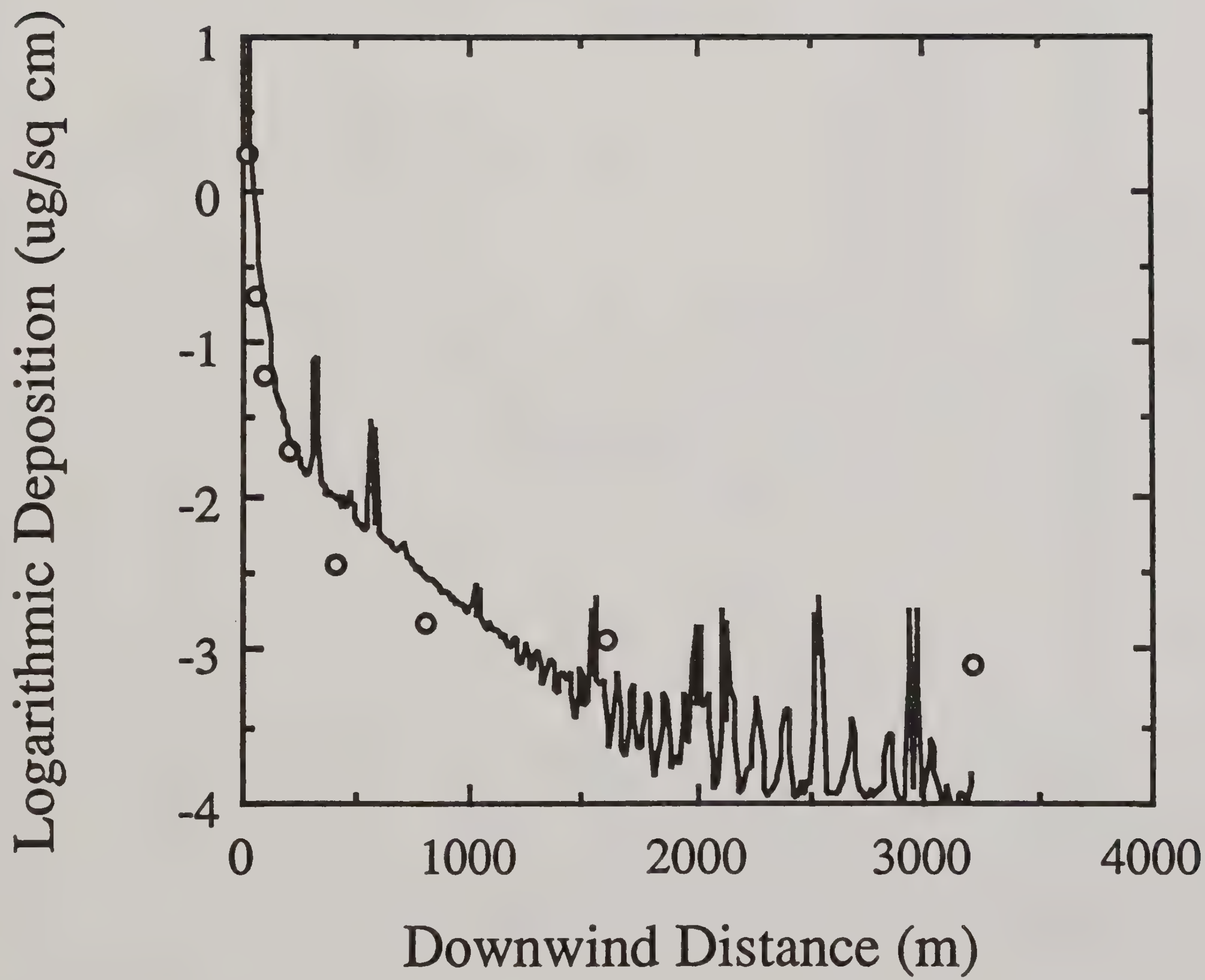

Figure 13. Comparison of the revised near-wake model prediction of FSCBG with the Desert Ranch data of Semmes, Cromwell and Shoup (1990).

5. Conclusions and Recommendations

This paper has reviewed the applicability of FSCBG to the prediction of downwind drift. Its most significant conclusion is that model predictions, with some straightforward model modifications, can be made to compare with fully documented field data sets. With results (published elsewhere) confirming the prediction ability of the model for in-swath conditions, this result suggests that the FSCBG model is able to handle any aerial application need by users familiar with the model.

Several recommendations present themselves:

1. When dealing with field data, the accuracy of the field measurements should always be confirmed. A comparison with FSCBG predictions makes little sense if the predictions continue to fall off downwind (as they should) while the data levels off. It is unreasonable to accept laboratory data that falls below a given threshold, or levels off at a given threshold, and make model comparisons against this data. Because of the logarithmic scale plot, very small numbers appear important, and differences between small numbers look significant. In the comparisons presented here, most of the released material has deposited near the aircraft flight lines; no more than five percent of it drifts to significant distances downwind.

2. Some of the modeling in FSCBG (such as wind speed profile and turbulence level) are a consistent application of accepted field observations. Any specific field trial may not fall within this norm. If the default approach does not recover sufficient accuracy of predictions with FSCBG, some modifications to field inputs should be experimented with, in an attempt to bracket the predicted results (this is a procedure used extensively by the Canadians, as suggested in Mickle 1987). Expansion of the drop size distribution at the smaller drop sizes must be considered.

3. Incompletely documented field data should not be used in validation studies without a clear understanding of their limitations. FSCBG may produce considerable inconsistency, especially if the user makes numerous and important input assumptions. The release height is a critical input parameter, and must be known accurately.

4. The importance of discretizing the drop size distribution into sufficiently small classes, including all nozzles in the simulation, and carefully monitoring the hand-off from near wake to far wake, cannot be understated. These features are expected to be implemented into a forthcoming version of FSCBG.

5. Still, it is the skill, understanding and resourcefulness of the user that must come into play, especially in simulation calculations of significant downwind drift scenarios. The user level-of-awareness must always be maintained by training and/or refresher sessions on the model, and through user group interaction and communication.

6. References

Akesson, N. B., R. K. Hitch and A. W. Jones. 1992. An analysis of airborne transport of pesticides from large scale aerial applications. Presented at the 26th annual convention of the NAAA. Las Vegas, NV.

Anderson, D. E., D. R. Miller, Y. Wang, W. G. Yendol, K. Mierzejewski and M. A. McManus. 1992. Deposition of aerially applied Bt in an oak forest and its prediction with the FSCBG model. *Journal of Applied Meteorology* 31: 1457-1466.

Barry, J. W., P. J. Skyler, M. E. Teske, J. E. Rafferty and B. S. Grim. 1993. Predicting and measuring drift of *Bacillus thuringiensis* sprays. *Environmental Toxicology and Chemistry* (to appear).

Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. AGDISP: the aircraft spray dispersion model, code development and experimental validation. *Transactions of the ASAE* 32: 327-334.

Bird, S. L. 1992. A compilation of aerial spray drift field study data for low-flight agricultural applications. U. S. Environmental Protection Agency Internal Report.

Bjorklund, J. R., C. R. Bowman and G. C. Dodd. 1988. User manual for the FSCBG aircraft spray and dispersion model, version 2.0. Report No. FPM 88-5. USDA Forest Service. Davis, CA.

Boyle, D. G., J. W. Barry, C. O. Eckard, W. T. Taylor, W. C. McIntyre, R. K. Dumbauld and H. E. Cramer. 1975. DC-7B aircraft spray system for large-area insect control. Report No. DPG-DRC980A. U. S. Army Dugway Proving Ground. Dugway, UT.

Crabbe, R. S., S. Davis, L. Elias and M. K. Krzymien. 1982. Field study of the effects of atmospheric stability on target deposition and effective swath widths for aerial forest sprays in New Brunswick: part 1. Report No. NRC NAE LTR-UA-61. National Research Council of Canada.

Curbishley, T. B. and P. J. Skyler. 1989. User manual -- Forest Service aerial spray computer model FSCBG (PC). Report No. FPM 89-1. USDA Forest Service. Davis, CA.

Dumbauld, R. K., J. R. Bjorklund and S. F. Saterlie. 1980. Computer models for predicting aircraft spray dispersion above and within forest canopies. Report No. 80-11. USDA Forest Service. Davis, CA.

Esterly, D., C. Hermansky, D. Valcore and B. Young. 1993. The Spray Drift Task Force atomization program. Presented at the Sixth Annual Conference on Liquid Atomization and Spray Systems ILASS-Americas 93. Worcester, MA. pages 47-49.

Gaidos, R., M. Patel, D. Valcore and R. Fears. 1990. Prediction of spray drift deposition from aerial applications of pesticides. Paper No. AA90-007. NAAA/ASAE Joint Technical Session. Reno, NV.

Guttman, I., S. S. Wilks and J. S. Hunter. 1971. Introductory Engineering Statistics second edition. John Wiley and Sons. New York. 548 pages. see page 103.

Mickle, R. E. 1987. A review of models for ULV spraying scenarios. Proceedings of Symposium on the Aerial Application of Pesticides in Forestry. National Research Council of Canada. 179-188.

Mugele, R. and H. D. Evans. 1951. Droplet size distributions in spray. *Industrial and Engineering Chemistry* 43: 1317-1324.

Picot, J. J. C., D. J. Wallace and D. D. Kristmanson. 1987. The PKBW model for prediction of aerial spraying deposition and drift. Proceedings of Symposium on the Aerial Application of Pesticides in Forestry. National Research Council of Canada. 161-170.

Rafferty, J. E. and J. F. Bowers. 1989. Comparison of FSCBG2 and FSCBG3 aerial spray model predictions with field measurements. Report No. DPG-FR-90-001. U. S. Army Dugway Proving Ground. Dugway, UT.

Rafferty, J. E. and J. F. Bowers. 1993. Comparison of FSCBG spray model predictions with field measurements. *Environmental Toxicology and Chemistry* 12: 465-480.

Rafferty, J. E., R. K. Dumbauld, H. W. Flake, J. W. Barry and J. Wong. 1982. Comparison of modeled and measured deposition for the Withlacoochee spray trials. Report No. 83-1. USDA Forest Service. Davis, CA.

Rafferty, J. E. and B. S. Grim. 1992. A canopy penetration experiment in Gambel oak. Presented at the Society of Environmental Toxicology and Chemistry (SETAC) Annual Meeting. Cincinnati, OH.

Ray, J., B. Richardson, A. Vanner and N. Davenhill. 1993. Definition of minimum drift application techniques using FSCBG. Paper No. 931102. ASAE-CSAE International Summer Meeting. Spokane, WA.

Richardson, B. 1991. Research and future needs related to the FSCBG and AGDISP computer models: a New Zealand perspective. New Zealand Forest Research Institute Working Paper.

Richardson, B., J. Ray, A. Vanner, K. Miller and N. Davenhill. 1993. Measured and modeled spray drift from three nozzle types following aerial application of a herbicide simulant. New Zealand Forest Research Institute Draft Report.

Semmes, R. H., R. P. Cromwell and W. D. Shoup. 1990. Downwind transport of aerially applied sprays under high temperature, high humidity conditions. *Applied Engineering in Agriculture* 6: 257-261.

Skyler, P. J. and J. W. Barry. 1990. Compendium of drop size spectra compiled from wind tunnel tests. Report No. FPM 90-9. USDA Forest Service. Davis, CA.

Teske, M. E. 1992. Correlation of the USDA Forest Service drop size distribution data base. Report No. FPM 92-7. USDA Forest Service. Davis, CA.

Teske, M. E. and J. W. Barry. 1993. Parametric sensitivity in aerial application. *Transactions of the ASAE* 36: 27-33.

Teske, M. E., K. P. Bentson, R. E. Sandquist, J. W. Barry and R. B. Ekblad. 1991. Comparison of FSCBG model predictions with Heather seed orchard deposition data. *Journal of Applied Meteorology* 30: 1366-1375.

Teske, M. E., J. F. Bowers, J. E. Rafferty and J. W. Barry. 1993. FSCBG: an aerial spray dispersion model for predicting the fate of released material behind aircraft. *Environmental Toxicology and Chemistry* 12: 453-464.

Teske, M. E. and T. B. Curbishley. 1991. Forest Service aerial spray computer model FSCBG version 4.0 user manual. Report No. FPM 91-1. USDA Forest Service. Davis, CA.

Yates, W. E., N. B. Akesson and H. H. Coutts. 1967. Drift hazards related to ultra-low-volume and diluted sprays applied by agricultural aircraft. *Transactions of the ASAE* 9: 628-632, 638.

Yates, W. E., N. B. Akesson and R. E. Cowden. 1974. Criteria for minimizing drift residues on crops downwind from aerial applications. *Transactions of the ASAE* 17: 627-632.